U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-269 547

Evaluation of Exhaust Emission from a Truck During Road Route and Mode Cycle Operation. Feasibility Study

Ethyl Corp, Ferndale, Mich

Prepared for:

Public Health Service, Ann Arbor, Mich Div of Air Pollution

Jul 66

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. PB269547

4. Title and Subtitle Evaluation of Exhaust Emission From a Truck During Road Route and Mode Cycle Operation- Feasibility Study	5. Report Date July 1966 6.
7. Author(s) Ethyl Corporation	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Ethyl Corporation 1600 West Eight Mile Ferndale, Michigan 48220	10. Project/Task/Work Unit No. 11. Contract/Grant No. PH 86-64-155
12. Sponsoring Organization Name and Address Division of Air Pollution U.S. Public Health Service Ann Arbor, Michigan 48105	13. Type of Report & Period Covered Feasibility Study 14.

15. Supplementary Notes

16. Abstracts

The basic objective of this feasibility study is to determine whether or not a truck operated on a mode cycle designed to closely simulate actual city operation will or will not give exhaust emissions that reasonably duplicate those obtained during the road operation of the vehicle. The information obtained in this project shows that this duplication of actual exhaust emission in road route operation is feasible. The information obtained in this study on one truck will provide data on which to base the second phase of the overall survey of truck and bus emission.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Motor vehicles
Exhaust emissions
Trucks

17b. Identifiers/Open-Ended Terms

Road route operation
Mode cycle operation

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	UNCLASSIFIED	21
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 7182-P74

PB 269 547

GR66-37

FEASIBILITY STUDY

EVALUATION OF EXHAUST EMISSION FROM A TRUCK DURING ROAD ROUTE AND MODE CYCLE OPERATION

Prepared for

U. S. PUBLIC HEALTH SERVICE

under

Contract No. PH 86--64-125

by

ETHYL CORPORATION
Ferndale, Michigan 48220

JULY 1966

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	TEST PREPARATION	2
III.	TEST PROCEDURES	4
IV.	TEST DATA	6
V.	DATA ANALYSIS	10
VI.	DISCUSSION OF RESULTS	11
VII.	CONCLUSIONS	14

I. INTRODUCTION

The basic objective of this feasibility study is to determine whether or not a truck operated on a mode cycle designed to closely simulate actual city operation will or will not give exhaust emissions that reasonably duplicate those obtained during the road operation of the vehicle.

The information obtained in this study on one truck will provide data on which to base the second phase of the overall survey of truck and bus emission. The first phase, which was completed under contract PH 86-62-12, resulted in the accumulation of extensive data on the modes of operation of commercial trucks and buses in several cities. The second phase of this work will involve measurement of the exhaust emissions from a large number of trucks run under conditions that duplicate the operating conditions found in the first phase. However, before proceeding with the second phase, a study was considered necessary to show whether this simulation of actual truck operation by means of a mode cycle was feasible.

For the most expeditious handling of this work, a contractual arrangement for a cooperative program involving the facilities and personnel of the Public Health Service (PHS), Division of Air Pollution, and of Ethyl Corporation was set forth. In execution of this program, the PHS supplied the analytical facilities and vehicle proportional sampling equipment. Ethyl supplied the test vehicle and other necessary equipment. Each of the cooperating parties supplied the necessary personnel for operation of their respective equipment. All test work was done in the Detroit area.

A basic objective was to select a road route where the mode of operation of a specific truck under normal city driving conditions was similar to the mode of operation of the average truck in this weight class based on data obtained in Los Angeles (Contract PH 86-62-12).

The plan was to perform all route driving tests during a one-week period in the summer of 1964. During the next month, a mode cycle would be developed from the route data. Following this, the mode cycle exhaust emission data would be obtained during the next two weeks.

However, due to a number of unavoidable delays caused by weather and poor driving conditions, the actual test work was extended over a period of one year instead of a few months as intended.

II. TEST PREPARATION

Route Selection -- To carry out the objective of this study, the selection of a route typical of normal city driving was necessary. This selection, done cooperatively by people from PHS and from Ethyl, was made in such a way as to reflect vehicle operation in business and residential areas and on arterial highways as found for trucks operated in the Los Angeles survey. During route selection, modes of vehicle operation were obtained for a number of different short routes. Inspection of the data indicated how the routes could be best combined to give the desired modes for agreement with the Los Angeles data for trucks of the weight class used in this study.

The final selected route was about 10 miles long and was comprised of three separate parts. The first part of the route was in Birmingham, Michigan, and consisted of roads passing through a combination of residential and shopping areas. The second part was in Royal Oak, Michigan, and was a combination of shopping and business areas. The third part was in Ferndale, Michigan, and consisted of operation on arterial highways passing through off-street business areas. In the driving periods between the three sections of the route, the data recording equipment in the test truck was not operated. Thus, the total data accumulated related to driving conditions during the three separate parts of the route only. This selected combination of routes was called the Birmingham route.

Equipment -- The PHS supplied the following equipment for carrying out the program.

1. A proportional sampler and plastic bags for collecting all necessary exhaust gas samples and for recording the amount of air flow through the engine carburetor.

2. Mobile laboratory for determining the concentration of hydrocarbons (by infrared and flame ionization), carbon dioxide, carbon monoxide and nitrogen oxides (Saltzman method) collected in the bag samples.

3. A Speed-Load-Acceleration-Variables-Encoder (SLAVE) unit for recording modes of vehicle operation. (Equipment made by Ethyl for PHS under Contract No. PH 86-62-12).

Ethyl Corporation supplied the following equipment:

1. A 1953 Chevrolet 1-1/2 ton, 4-speed manual transmission stake truck with an unloaded weight of 5250 pounds equipped with a 235-cubic inch Chevrolet engine. Sand bags were added to the truck to bring its total weight to 8250 pounds. Prior to start of the program, the truck engine was carefully tuned and inspected. Cylinder compression pressures, spark plug firing, and carburetor operation were analyzed to see that the engine was in good mechanical condition. Sufficient fuel was set aside to ensure that the truck would be operated on the same fuel throughout the test program.

2. A Varian two-pen strip chart recorder with a chart speed of 6 inches per minute. Engine speed and manifold vacuum transducers were supplied to operate the pens.

3. Strip charts for the Varian recorder with a record on the chart showing the engine speed and manifold vacuum for the mode cycle developed on the basis of the route work.

4. Power generators and converters for operation of all equipment and instruments installed on the truck.

5. A dual-control mechanism for actuating the brakes and foot throttle by an observer in the truck sitting beside the driver.

6. A fifth-wheel assembly and stopwatch for measuring average vehicle speed.

III. TEST PROCEDURES

1. Instrument Calibrations

Prior to the start of each test run, the integrator counters for recording air flow through the carburetor and exhaust gas flow into the sample bag were adjusted to give nearly the same number of counts per unit of time at 0.2, 0.4 and 0.8 inches H_2O pressure drop. Following this calibration, the proper amount of nitrogen was flowed into the sample bag to give an estimated final dilution ratio of about 3 parts nitrogen to 1 part exhaust gas sample.

2. Road Route

In all road work, the selected Birmingham route was used. This route was deliberately selected to be representative of the mode of operation of the average truck in Los Angeles for the weight class of the vehicle used in this study. The truck was driven about 10 miles to the starting point of the test run. Thus, the truck was in a hot-start condition before each test. At the start of the run, the proportional sampler, SLAVE unit and fifth wheel were put into operation. The vehicle was then driven over the selected test route following the normal flow of traffic within the capabilities of the truck. One addition to the normal traffic pattern was to have the truck idle for 2 minutes at the end of each of three parts to the route. This provided a total idle time of 6 minutes in the route operation. This way the percent idle time was made to compare favorably with the idle time found for trucks of this weight class in the Los Angeles survey.

The end of the route terminated at the Ethyl Laboratories where the PHS mobile laboratory was located. The total residence time of the exhaust gases in the plastic sample bag prior to their analysis was equal to the time required to make the run, or about 1/2 hour.

Analyses were made in the mobile laboratory for carbon dioxide, carbon monoxide, and hydrocarbon by infrared. Hydrocarbon concentrations as carbon were also determined by flame ionization. Two samples were

obtained for NO_x analysis. The PHS analysed one sample by the Saltzman method; Ethyl analysed the other sample by the phenol disulphonic acid method.

Observed pollution concentrations were corrected for the measured N_2 dilution in the sample bag. The corrected values corresponded to the concentration of pollutants in the engine exhaust. The entire Birmingham route operation was repeated 10 times in August 1964, 10 times in December 1964, and 2 times in July 1965.

The tape records from the SLAVE instrument were processed by Ethyl on a program developed under Contract No. 86-62-12. This compiled all the data on the tape record into 9 major categories on a percent engine revolution basis, 139 subcategories on a percent duration basis, and 72 possible combinations of changes from category to category on a percent of total changes basis.

3. Mode Cycle

The first step in preparation of a mode cycle was to use the technique described in the prior report for the truck and bus survey (Contract No. PH 86-62-12). This approach gave a mode cycle involving about 18 different operating modes described in terms of speed and manifold vacuum. This information was drawn on a blank chart used in the 2-pen Varian recorder. The objective was to drive the truck so as to follow the engine speed and manifold vacuum shown on the chart. When an attempt was made to do this, however, the recording pens showed that a poor reproduction of the desired record was obtained.

After some experimenting and second-by-second examination of the data from the SLAVE unit, the reason for the inability to follow the mode cycle became quite clear. During actual vehicle operation, many of the modes were accomplished with the vehicle in various gear ratios. The computer, in assembling the data for the various modes, gets the data on a straight engine revolution basis and makes no allowance for engine gear ratios. Thus, the average speed-time relationships indicated by the computer are realistic as far as engine speed is concerned, but

require interpretation in terms of the gears used in order to provide suitable mobility to the truck.

The solution to this problem was to make a close examination of the second-by-second printout of a data tape record for the Birmingham route that best represented the average of the ten runs made in August 1964. The computer printout showed the engine speed and manifold vacuum in graphical form versus time. From this record, all gear shifts were easily identified. The record showed:

1. Speed changes, with the vehicle in gear, take place very much more rapidly than speed changes in high gear (straight-thru drive or 4th gear).

2. Large changes in speed almost always occur while shifting gears.

3. Most high gear speed changes are quite small and occur quite slowly corresponding to the normal changes in vehicle speed while following traffic conditions.

The tape data printout showed very clearly that an average value for engine acceleration would be physically impossible to duplicate by a vehicle operating in high gear only. The next operation, therefore, was to assign to the theoretical modes indicated by the computer data those which most likely were accomplished during gear shifting and those which were performed in high gear.

Examination of the second-by-second printout from the computer revealed that each individual operation during a gear shift from second to fourth required anywhere from 2 to 5 seconds. On this basis, about six typical gear shift patterns were developed. An attempt was made in arranging these patterns to utilize the speed ranges and major categories that were actually experienced by the truck as shown by the results from the SLAVE unit.

Further tests on the truck showed that, when in high gear, the acceleration during full throttle operation did not exceed 60-65 rpm per second. Likewise, during part throttle operation, the accelerations did

not exceed 40-45 rpm per second. Mild decelerations were about 40 rpm per second and heavy decelerations 100 + rpm per second.

Based on selected gear shift patterns and reasonable values for acceleration and deceleration in high gear, as well as known changes from one major mode to the next, an attempt was made to construct a reasonable mode cycle. Since the above factors impose a great many limiting conditions on the mode cycle development, it is practically impossible to obtain an exact fit between cycle operation and that dictated by the computer printout based on the actual Birmingham route. The final approximation developed is listed in Table 2. Driving time for the mode cycle is 587.5 seconds or somewhat less than 10 minutes. Graphical illustration of the cycle in terms of engine speed and manifold vacuum is illustrated in Figure 1 which is a reproduction of the strip chart used in the Varian recorder. Since the chart travelled at a speed of 8 inches per minute, the distance between any two adjacent vertical lines on the chart represents 1.875 seconds. On the vertical scale, the distance between any two adjacent horizontal lines represents 50 rpm.

Mode Cycle Work

In December 1964, the mode cycle tests were conducted on the parking lot of the Hazel Park Race Track. This is a level area about 1/4 mile square. The truck was operated in a large loop around the circumference of the lot. In July 1965, the work was conducted on the race track at the Michigan State Fair Grounds. This is a level track and is about one mile in circumference. Driving conditions at the two tracks should be reasonably identical.

For the mode cycle tests, the truck was fitted with dual control for the foot throttle and brakes. The driver of the truck steered the vehicle and made all necessary gear shifts in accordance with the selected gear shift patterns previously described. As soon as the gear shift operation was over, another operator sitting beside the driver controlled the throttle and brakes. The second operator was relieved of all responsibility of steering the vehicle and could concentrate all his

attention on operating the vehicle in such a manner as to best follow the cycle indicated on the chart. With practice, operators became proficient in this operation of the truck. A typical example of the engine speed and manifold vacuum record obtained is shown in Figure 1.

During the mode cycle tests, all the instrumentation used in the route operation for obtaining an exhaust gas sample and for recording vehicle performance on a tape record were in service. In addition, all data computations were performed in the same manner as during the route tests.

IV. TEST DATA

1. Road Route

A total of 24 runs was made using the Birmingham route; 12 in the summer of 1964, 10 in the winter of 1964, and 2 in the summer of 1965. Of the winter runs, two were made on an arterial highway at a relatively high speed. Three runs were not considered to be of value because of snow and difficult driving conditions (not shown in Tables). And two were made late at night where traffic conditions were so light that the driving pattern was quite different from normal daytime driving. The data for the night runs, and the operation on an arterial highway are shown in Table 5. The data for all the rest of the Birmingham runs are shown in Tables 3 and 4. In each table, values for the 25 test variables are indicated. It should be noted that all original test mile data were corrected by the ratio of 1.5/1.3, or 1.154. This was necessary because inadvertently the fifth wheel was equipped with a gear ratio of 1.300. The correct gear ratio for 1000 counts of the fifth wheel odometer per mile is 1.500. This caused a corresponding correction to the indicated values in the tables for average miles per hour and exhaust pollutants on a mass basis.

A comparison of the major vehicle modes on a percent engine revolution basis between the Los Angeles mode data for 15 different trucks in 6,000 to 10,000 lbs GVW and the 1964 summer Birmingham

data for 10 runs on the same truck is shown in the following table.

TABLE 1

Comparison of Los Angeles Modes with Birmingham Modes on Route Selected to Match California Data

Modes	Range of L. A. Data	Percent Engine Revolutions: Avg. L. A. data	Percent Engine Revolutions: Avg. Birmingham Data
IDL	0.02 -- 23.26	7.27	7.50
CRU	11.92 -- 43.62	25.93	28.56
FTC	0.39 -- 12.18	2.75	3.13
PTA	11.60 -- 29.26	18.66	17.48
FTA	7.50 -- 24.29	15.31	14.65
MDE	3.50 -- 13.77	8.30	9.44
HDE	11.59 -- 25.48	19.40	18.06
CTA	0.24 -- 2.19	0.77	1.07
FTD	0.34 -- 3.42	1.59	1.10

A. Mode Cycle Data

A total of 30 runs were made on a level track; 22 in winter of 1964 and 8 in the summer of 1965. A large number of runs were made in the winter mode cycle work because of the tendency for the level of exhaust emission to increase with repeated runs in the same day. The reason for this increase was not solved. This phenomenon did not seem to occur during the summer mode cycle runs with the same truck.

The complete data obtained in all mode cycle tests are shown in Table 6 for the 1964 winter runs, and Table 7 for the 1965 summer runs. As in the road route tables, a total of 25 test items of interest is listed for each run.

V. DATA ANALYSIS

For the objective of this program, it is unnecessary to analyse all the data obtained. The essential data are represented by the 1964 summer road route runs (Table 5) and the 1965 summer mode cycle runs (Table 7). The average for each of these two groups of runs is shown in Table 8. Averages for data shown in Table 6 have been included in Table 8 merely to demonstrate the high variability of the information due to tendency for emissions to increase with repeated, consecutive tests during the 1964 mode cycle runs.

For each of the 25 test variables, Table 8 shows the standard deviation, the mean, and their percent ratio for the 1964 summer road tests, the 1964 winter track tests, and the 1965 summer track test. A listing is also shown for the difference between the means for the 1965 summer track tests and for the 1964 summer route tests as a percentage of the latter. One would expect, where this difference between the means is small relative to the standard deviation, both expressed as a percentage of the mean for the 1964 summer route tests, the probability is low that the two means are not representative of the same population.

A nonparametric median test for a determination of the central tendencies of the 1965 summer route data and the 1965 summer mode cycle data is shown in Table 8. The value (n. s.) in the table indicates that the two groups of data for any one variable are not significantly different at the 95% confidence level. The statistical analysis presented in the table was prepared by Mr. Jon Hill of the U. S. Public Health Service.

Although the nonparametric test is not as strong as a parametric procedure, this method was used because the accuracy of the derived probability statement is independent of the shape of the population from which the sample is drawn. This approach seemed necessary because of the apparent non-homogeneity of the data.

VI. DISCUSSION OF RESULTS

Based on the statistical calculations shown in Table 6, the following trends are indicated:

1. The exhaust emissions on a concentration basis for the 1964 summer route tests are not significantly different from the 1965 summer mode cycle tests.

2. The average driving speed in the two tests was not significantly different.

3. The air consumed by the engine (SCF/mile) and the corresponding amount of exhaust gases (SCF/mile) were significantly different.

4. The exhaust emissions on a pounds per mile basis were significantly different for all pollutants except the hydrocarbons.

5. On a percent revolutions basis, there are no significant differences in cruise, part throttle, acceleration, and mild deceleration representing slightly more than 50% of the total engine revolutions. Significant differences were found for all other modes of vehicle operation.

The change from no significance difference of the pollutant on a concentration basis to a significant difference on a mass basis can be accounted for by the larger cubic feet of exhaust gases per mile in the mode cycle tests. The reason that the hydrocarbons still showed no significant difference on a mass base is probably due to the fact that these pollutants were somewhat less in the mode cycle tests. Thus, in this case, the higher cubic feet of exhaust in the mode cycle tests was partially compensated for by the corresponding lower concentration values.

An item of some interest is the higher cubic feet of exhaust in the mode cycle tests. Since the mode cycle tests were done on a level track and the road tests were not, the opposite circumstance might be expected. Also the agreement between the average vehicle speeds in both tests eliminates this as a possibility in explaining the difference.

However, the difference between the modes of vehicle operation in the two tests does offer an interesting explanation. In general, the extremes of vehicle operation (full throttle cruise, full throttle acceleration, heavy deceleration, closed throttle acceleration, and full throttle deceleration) were significantly different in the two series of tests. This tends to indicate that the test drivers, in endeavoring to follow a prescribed series of driving conditions in the mode cycle work, were driving abnormally. That is, in an attempt to follow a difficult driving cycle, the normal tendency is for the driver to overcompensate when the desired driving pattern is not obtained (see Figure 1). Finally, this results in a continuous series of compensations with a resultant emphasis on driving extremes, as found. These extremes, similar to driving on roads with varying grades or in heavy traffic, result in a relative increase in the air consumed by the engine per mile of operation and explains the higher cubic feet of exhaust in the mode cycle tests.

VII. CONCLUSIONS

1. While the correlations between a road route test and a mode cycle test designed to simulate the driving conditions of the route were not perfect, nevertheless a high degree of correspondence in exhaust pollutants was obtained in the two tests. It is believed that, in this work, the degree of correlation achieved in exhaust emission between route and mode cycle operations is better than in any previous similar studies.

2. It is possible by the proper selection of routes totalling about 10 miles within a given city to duplicate reasonably well the mode of operation of trucks in actual service.

3. The information obtained in this project shows that the duplication of actual exhaust emission in route operation by a mode cycle is feasible and that the results will be of considerable value in a further program to evaluate the exhaust emissions from a large sample of trucks.

4. In developing driving mode cycles to simulate actual driving conditions, cycles should not be required that are beyond the ability to accomplish by a good driver. If this is done, it will result in over-compensations in vehicle operation and poor vehicle performance. Efforts should be made to arrive at the optimum of driving complexity to meet the desired modes of vehicle operation but not unduly exceed the capabilities of the driver to follow the selected modes. A reasonably optimum resolution of this problem is considered of prime importance in further truck exhaust emission studies.

Table 8

Mode Cycle Selected to Represent Birmingham Route

Category	Speed, rpm	Manifold Vac, in Hg.	Seconds	Gear Shift*
IDL	600	15-21	16	N
PTA	600-1500	6-21	3	2
PTA	1500-2300	6	1	2
MDE	2300-1300	6-21	2	3
PTA	1300-2300	6	5	3
HDE	2300-1500	21	2	4
CRU	1500	6	6.5	4
PTA	1500-1700	6	1.0	4
PTA	1700-1880	6-21	3.5	4
CRU	1880	6	6.5	4
PTA	1880-1980	6-21	2.5	4
CRU	1980	6	6.5	4
PTA	1980-2080	6-21	2.5	4
CRU	2080	6	6.5	4
HDE	2080-1150	21	6.0	4
CRU	1150	6	5.5	4
MDE	1150-900	6-21	1.5	4
CRU	900	6	2.5	4
HDE	900-600	21	1.5	4
IDL	30	15-21	16	N
PTA	600-2500	6-21	5.0	2
MDE	2300-1250	6-21	2.0	3
PTA	1250-2300	6	5.0	3
HDE	2300-1500	21	1.0	4
MDE	1500-1150	6-21	1.0	4
PTA	1150-1270	6-21	1.0	4
CRU	1270	6	6.5	4
PTA	1270-1390	6-21	3.0	4
CRU	1390	6	6.5	4
PTA	1390-1510	6-21	3.0	4
PTA	1510-1690	6	3.0	4
MDE	1690-1390	6-21	2.0	4
CRU	1390	6	6.5	4
HDE	1390-1090	21	2.5	4
MDE	1090-900	6-21	1.5	4
HDE	900-600	21	2.5	4
IDL	600	15-17	16.0	N
PTA	600-1150	6-21	2	2
PTA	1150-2300	6	3	2
MDE	2300-1750	6-21	2.0	3
PTA	1250-2300	6	4.0	3
MDE	2300-1500	6-21	2.0	4
HDE	1500-1150	21	4.0	4
CRU	1150	6	2.5	4
PTA	1150-1270	6-21	1.0	4
CRU	1270	6	6.5	4
PTA	1270-1400	6-21	3.0	4
HDE	1400-1150	21	1.0	4
CRU	1150	6	2.5	4
PTA	1150-1400	6	5.0	4
PTA	1400-1520	6-21	3.0	4

Table A (continued)

Category	Speed, rpm	Manifold Vac., in Hg.	Seconds	Gear Shift*
HDE	1580-1080	21	5.5	4
MDE	1080-940	6-21	2.0	4
HDE	940-600	21	2.5	4
IDL	600	15-21	16.0	N
PTA	600-2300	6-21	4.0	2
MDE	2300-1400	6-21	2.0	3
PTA	1400-2350	6	5.0	3
HDE	2350-1850	21	2.0	4
MDE	1850-1150	6-21	2.0	4
CRU	1150	6	2.5	4
PTA	1150-1320	6-21	3.0	4
CRU	1320	6	6.5	4
PTA	1320-1500	6-21	4.0	4
CRU	1500	6	6.5	4
HDE	1500-1300	21	2.0	4
MDE	1300-1850	6-21	1.5	4
PTA	1850-1370	6-21	3.0	4
CRU	1370	6	6.5	4
MDE	1370-1300	6-21	1.5	4
CRU	1300	6	6.5	4
HDE	1300-700	21	5.5	4
MDE	700-600	6-21	2.0	4
IDL	600	15-21	16.0	N
PTA	600-1850	6-21	2.0	2
PTA	1850-2350	6	2.0	2
MDE	2350-1400	6-21	2.0	3
PTA	1400-2350	6	5.0	3
MDE	2350-1850	21	2.0	4
PTA	1850-1370	6-21	3.0	4
MDE	1370-1300	6-21	1.5	4
PTA	1300-1420	6-21	3.0	4
CRU	1420	6	6.5	4
HDE	1420-1270	21	2.5	4
MDE	1270-1190	6-21	1.5	4
CRU	1190	6	2.5	4
HDE	1190-1080	21	2.0	4
MDE	1080-1000	6-21	2.0	4
HDE	1000-600	21	3.0	4
IDL	600	15-21	16.0	N
PTA	600-2300	6-21	5.0	2
MDE	2300-1400	6-21	2.0	3
PTA	1400-2300	6	4.0	3
MDE	2300-1850	6-21	2.0	4
PTA	1850-1370	6-21	3.0	4
CRU	1370	6	6.5	4
MDE	1370-1300	6-21	1.5	4
HDE	1300-1100	21	5.0	4
CRU	1100	6	2.5	4
HDE	1100-600	21	5.0	4
IDL	600	15-21	16.0	N
PTA	600-1150	6-21	2.0	2
PTA	1150-2350	6	3.0	2
MDE	2350-1400	6-21	2.0	3
PTA	1400-2350	6	4.0	3

Table A (continued)

Category	Speed, rpm	Manifold Vac, in Hg.	Seconds	Gear Shift*
HIE	0350-1150	21	5.0	4
CRU	1150	6	0.5	4
PTA	1150-1070	6-21	3.0	4
PTA	1070-1450	6	3.0	4
PTA	1450-1570	6-21	3.0	4
HIE	1570-1090	21	0.5	4
MIE	1070-1010	6-21	1.5	4
PTA	1010-1130	6-21	3.0	4
CRU	1130	6	0.5	4
MIE	1130-1050	6-21	1.5	4
HIE	1050-600	21	0.0	4
MIE	600-600	6-21	1.5	4
IDL	600	15-21	16.0	N
PTA	600-0300	6-21	5.0	2
MIE	0300-1400	6-21	2.0	3
PTA	1400-0300	6	5.0	3
HIE	0300-1050	21	0.0	4
PTA	1050-1370	6-21	3.0	4
CRU	1370	6	0.5	4
MIE	1370-1010	6-21	1.5	4
PTA	1010-1300	6-21	3.0	4
PTA	1300-1500	6	3.0	4
HIE	1500-1050	21	3.0	4
MIE	1050-1170	6-21	1.5	4
HIE	1170-600	21	1.0	4
IDL	600	15-21	16.0	4
PTA	600-0300	6-21	5.0	2
MIE	0300-1400	6-21	2.0	3
PTA	1400-0300	7	4.0	3
HIE	0300-1150	21	0.0	4
MIE	1150-1070	6-21	1.5	4
HIE	1070-600	21	0.5	4
IDL	600	15-21	16.0	4

* N = Neutral
2 = second gear
3 = third gear
4 = forth gear (straight through drive)

TABLE 4

BIRMINGHAM ROUTE DATA

		1964 WINTER RUNS					1965 SUMMER RUNS	
	Run No.	1337	1340	1341	1350	1351	1368	1369
	Date	12/8	12/10	12/10	12/14	12/4	7/28	7/28
1	HC-IR, ppmC	2907	2788	2480	3374	3001	3178	3429
2	HC-FID, ppmC	3941	3740	3296	4371	3993	4754	5129
3	CO, %	1.94	1.94	1.65	2.06	2.09	2.88	2.66
4	CO_2, %	11.85	12.58	11.85	12.47	12.53	11.14	11.03
5	O_2, %	4.13	3.26	3.39	3.99	4.67	2.62	2.95
6	NO_x, ppm (SAL/TZMAN)	1437	1571	1421	---	1467	840	859
7	NO_x, ppm (PDSA)	1515	1676	1480	---	1590	883	1025
8	Test Miles	13.59	13.60	13.62	12.55	13.62	13.9	13.6
9	MPH	19.1	20.6	18.2	19.8	19.8	20.7	17.5
10	AIR, SCF/mi	89.3	89.1	89.3	86.0	89.0	90.2	88.8
11	EXH, SCF/mi	85.9	84.7	85.7	81.8	84.6	86.7	85.5
12	HC-IR, lb/mi	.00884	.00852	.00765	.00993	.00914	.00956	.01034
13	HC-FID, lb/mi	.01208	.01140	.01017	.01272	.01215	.01482	.01577
14	CO, lb/mi	.1212	.1193	.1028	.1226	.1285	.1777	.1652
15	CO_2, lb/mi	1.154	1.218	1.161	1.166	1.213	1.103	1.0766
16	NO_x, lb/mi (SAL/TZMAN)	.01463	.01590	.01454	---	.0148	.00869	.00876
17	IDL	8.21	6.82	8.41	6.11	7.41	6.98	7.99
18	CRU	27.32	28.74	32.87	29.58	28.80	31.37	27.17
19	% FTC	2.53	2.16	2.41	2.26	2.20	1.73	2.21
20	ENG. FTA	17.17	15.42	19.26	19.44	16.97	22.34	20.97
21	REV. FTA	17.69	17.46	11.88	14.39	14.93	10.29	12.24
22	MDE	9.44	8.81	7.62	8.05	10.02	8.58	9.21
23	HDE	16.75	19.16	16.30	19.06	18.54	17.26	19.37
24	CTA	0.42	0.82	0.87	0.71	0.75	0.89	0.80
25	FTD	0.43	0.62	0.37	0.40	0.37	0.57	0.33

TABLE NO. 5

		NIGHT RUNS		ARTERIAL HIGHWAY	
		1964 WINTER		1964 SUMMER	
	RUN NO.	1930	1130	1910	1500
	DATE	12/8/64	12/9/64	8/20/64	8/20/64
1.	HC-IR, ppmC	8497	8788	1784	2574
2.	HC-FID, ppmC	9080	8959	2091	2898
3.	CO, %	1.69	1.71	0.98	1.19
4.	CO_2, %	12.66	13.09	12.30	12.87
5.	O_2, %	5.06	5.69	5.47	4.41
6.	NO_x, ppm (Saltzman)	1689	1591	1255	1434
7.	NO_x, ppm (PHOA)	1950	1892	1876	2040
8.	Test Miles	13.98	13.94	7.08	7.07
9.	MPH	28.1	21.6	42.3	41.0
10.	AIR, SCF/mi	87.1	89.1	77.5	77.1
11.	EXH, SCF/mi	82.6	84.4	73.0	72.3
12.	HC-IR, lb/mi	.007742	.00788	.00468	.0067
13.	HC-FID, lb/mi	.0090	.00899	.00549	.0060
14.	CO, lb/mi	.09952	.1049	.05199	.0594
15.	CO_2, lb/mi	1.195	1.267	1.085	1.065
16.	NO_x, lb/mi (Saltzman)	.0160	.01605	.0109	.0184
17.	TDL	6.60	7.79	0.86	1.19
18.	CRU	48.51	48.11	61.91	59.19
19. %	PTC	2.56	3.74	0.00	0.19
20. Neg.	PTA	10.07	14.46	9.35	12.27
21. Rev.	PTA	19.69	12.41	10.26	9.08
22.	MDE	7.25	5.44	7.37	6.70
23.	HDE	12.07	13.06	10.01	11.05
24.	CTA	0.71	0.86	0.00	0.00
25.	FTD	0.01	0.13	0.13	0.41

[illegible]

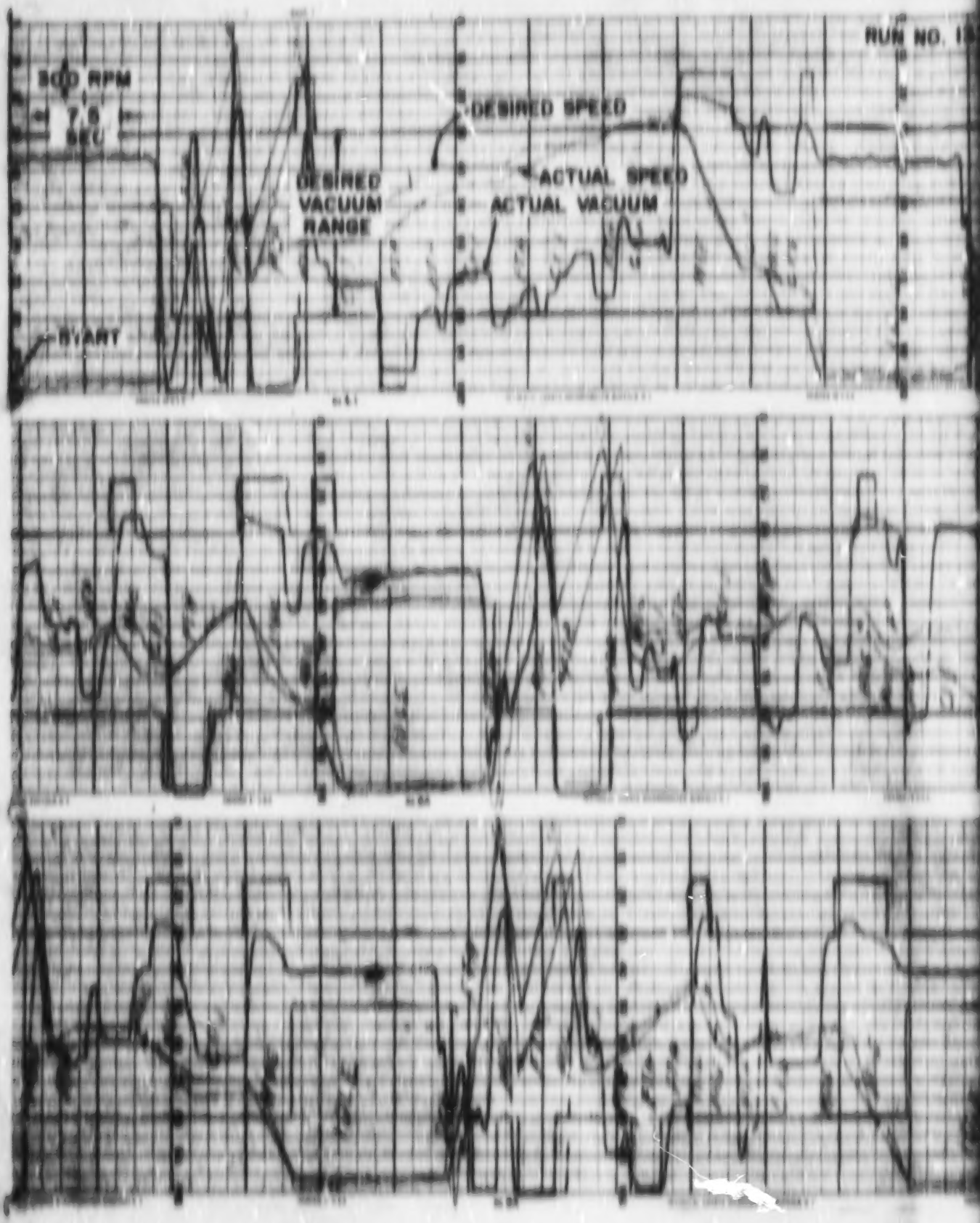
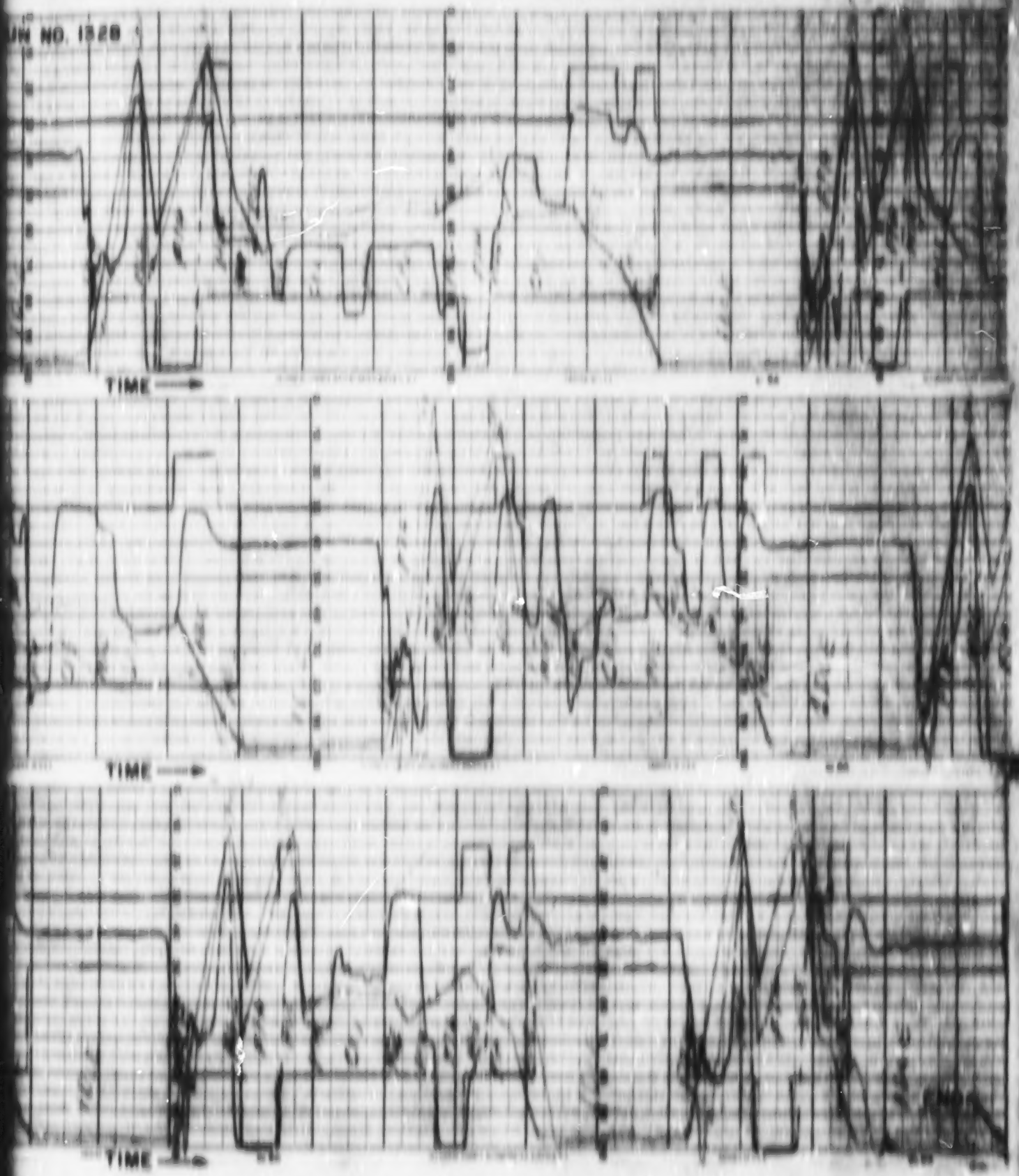


FIGURE 1 TYPICAL RECORD OF ENGINE SPEED AND



AND MANIFOLD VACUUM DURING MODE CYCLE OPERATION